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INTRODUCTORY REVIEW OF TARGET DISCRIMINATION CRITERIA

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60 Concord Street
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This report presents results of investigations to determine the validity of certain assumptions and criteria used in the development of the Sensor Performance Model (SPM), which is part of the Electro-Optical Tactical Decision Aids (EOTDA) software program. The investigations were based upon a literature review of works by John Johnson, Herschel Self, Lucien Biberman, David Schmieder and other authors knowledgeable in the electro-optical field. The investigations sought to answer several issues related to target discrimination criteria and the role of Johnson's criteria in defining target discrimination. Among the issues to be addressed were: 1) the levels of target discrimination, 2) the definition of each target discrimination level, 3) the definition of Johnson's criteria, 4) the use of Johnson's criteria in target discrimination, 5) the factors that influence the accuracy of Johnson's criteria and 6) the implication of Johnson's criteria inaccuracies on the application of these criteria to the Electro-Optical Tactical Decision Aids.

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INTRODUCTORY REVIEW OF TARGET DISCRIMINATION CRITERIA

INTRODUCTION

This report contains results of investigations undertaken by Dynamics Research Corporation (DRC) at the request of Phillips Laboratory, Geophysics Directorate, Hanscom AFB and is submitted in accordance with CDRL Item No. 212 of Contract F19628-89-D-0011. The purpose of the investigations was to determine the validity of certain assumptions and criteria used in the development of the Sensor Performance Model (SPM), which is part of the Electro-Optical Tactical Decision Aids (EOTDA) software program. The investigations were based upon a literature review of works by John Johnson, Herschel Self, Lucien Biberman, David Schmieder and other authors knowledgeable in the electro-optical field. The investigations sought to answer several issues related to target discrimination criteria and the role of Johnson's criteria in defining target discrimination. Among the issues to be addressed were: 1) the levels of target discrimination, 2) the definition of each target discrimination level. 3) the definition of Johnson's criteria, 4) the use of Johnson's criteria in target discrimination, 5) the factors that influence the accuracy of Johnson's criteria and 6) the implication of Johnson's criteria inaccuracies on the application of these criteria to the Electro-Optical Tactical Decision Aids.

BACKGROUND

DRC was initially requested to answer six questions related to the Electro-Optical Tactical Decision Aids Validation Plan. These questions were:

1. What are the Johnson Criteria that have been applied to EOTDA range calculations?

2. What are the definitions of detection, recognition, and identification? What is the role of "clutter" in these processes? Can we quantify clutter in a scene? What concepts do we need to define for measurements and validation? Models of targets with uniform thermal characteristics could be used to test MRT criteria. How can we test MDT with various stages of clutter?

3. What data parameters must be available or measured for our analysis?

4. Based on EOTDA sensitivity analyses, under what different weather events should the analysis be conducted (e.g. clear, fog, haze, precipitation, etc.?)

5. Do any current data sets have sufficient data for SPM validation?

6. What volume of data is needed to have a statistically representative analysis?

Questions 1, 2 and 4 were to be answered during the current fiscal year, while questions 3, 5 and 6, relating to TDA data, were to be deferred until FY'92. This report covers only questions 1 and 2.

Question 1, which addresses the Johnson criteria is covered in the Technical Discussion section of this report. Question 2, while addressed in the Technical Discussion section, is also covered in Appendix A with respect to the definitions. Appendix A contains additional definitions than those requested, since many of these terms are used extensively in the EOTDA literature. Appendix B contains a list of acronyms which have been collected from a variety of sources in the EOTDA literature.

TECHNICAL DISCUSSION

In the mid- and late-1950's the military was developing electro-optical image intensifiers which provided enhanced visual surveillance capabilities under conditions of limited visibility. These intensifiers permitted significant increases in visual target acquisition range and image display capability. The complexity of these intensifiers and associated target acquisitions systems required a methodology for evaluating performance characteristics. John Johnson (1) of the U. S. Army Engineer Research and Development Laboratories (ERDL), Fort Belvoir, Virginia presented a paper at the October 1958 Image Intensifier Symposium which addressed "methods and procedures for the solution of problems involving military visual surveillance through image intensifier devices under low light level conditions." The paper, entitled "Analysis of Image Forming Systems" contained results of experiments conducted at ERDL to determine the resolution required of a system to perform certain target interpretation processes identified by Johnson as detection, shape orientation, shape recognition, detail recognition and target identification. He also referred to these as "decision responses". These were regarded as distinct "degrees of freedom" or "states" of an image intensifier system. These "decision responses" are dependent upon "the characteristics of the optical message, the properties of the intensifier device, and the physiological response of the human readout processes".

The paper went on to develop a series of relationships between a number of variables in the "space domain" and the "space frequency domain". Johnson indicated that the "space domain" approach was tedious and cumbersome and had to be repeated for each view of each target of interest. The space frequency approach greatly simplified the analysis. However the abstract frequency spectra had to be related to real targets. Through a series of experiments using trained observers, Johnson was able to develop a method relating the "decision response" by normalizing resolved

line pairs for a critical target dimension. He found that the minimum resolution required for a particular "decision response" was nearly constant for a group of nine military targets. The results of these experiments are tabulated in Table 1. The data show that the minimum resolution required for a particular decision activity is a constant for nine military targets within a maximum error excursion of ±25%.

TABLE 1. OPTICAL IMAGE TRANSFORMATIONS

TARGET	Resolution - Line Pairs per Minimum Dimension			
Broadside View	Detection	Orientation	Recognition	Identification
Truck	.90	1.25	4.5	8.0
M-48 Tank	.75	1.2	3.5	7.0
Stalin Tank	.75	1.2	3.3	6.0
Centurion Tank	.75	1.2	3.5	6.0
Half-track	1.0	1.50	4.0	5.0
Jeep	1.2	1.50	4.5	5.5
Command Car	1.2	1.5	4.3	5.5
Soldier (Standing)	1.5	1.8	3.8	8.0
105 Howitzer	1.0	1.5	4.8	6.0
Average	1.0 ± .25	1.4 ± .35	4.0 ± .8	6.4 ± 1.5

These target transformations were found to be independent of contrast and scene signal to noise ratio as long as the contrast in the resolution chart was the same as the contrast in the complex target. These results indicated that complex military targets may be considered equivalent in a visual sense to repetitive resolution patterns of appropriate spatial frequencies for each decision level. The results are general, at least for the limited group considered, and are independent of distance. They simplify considerably the determinations of decision level activity in any imaging system, since it is only necessary to determine the angular resolution characteristic as a function of a few parameters. These transformations, which provided target discrimination criteria based upon resolution, gained widespread acceptance within the industry and became the accepted criteria for performance

measurement of optical systems. These criteria were referred to as the "Johnson Criteria".

The methodology developed by Johnson was simple and straight forward. A target was moved to a range where it was just barely detectable. A bar pattern was placed in the field of view and its spatial frequency was increased until it could barely be resolved at the same range, i.e. the number of lines on the bar pattern was increased until they could no longer be distinguished. The spatial frequency of the pattern was specified in terms of the number of lines in the pattern subtended by the object's minimum dimension as illustrated in Figure 1. The same methodology was used for orientation, recognition and identification.

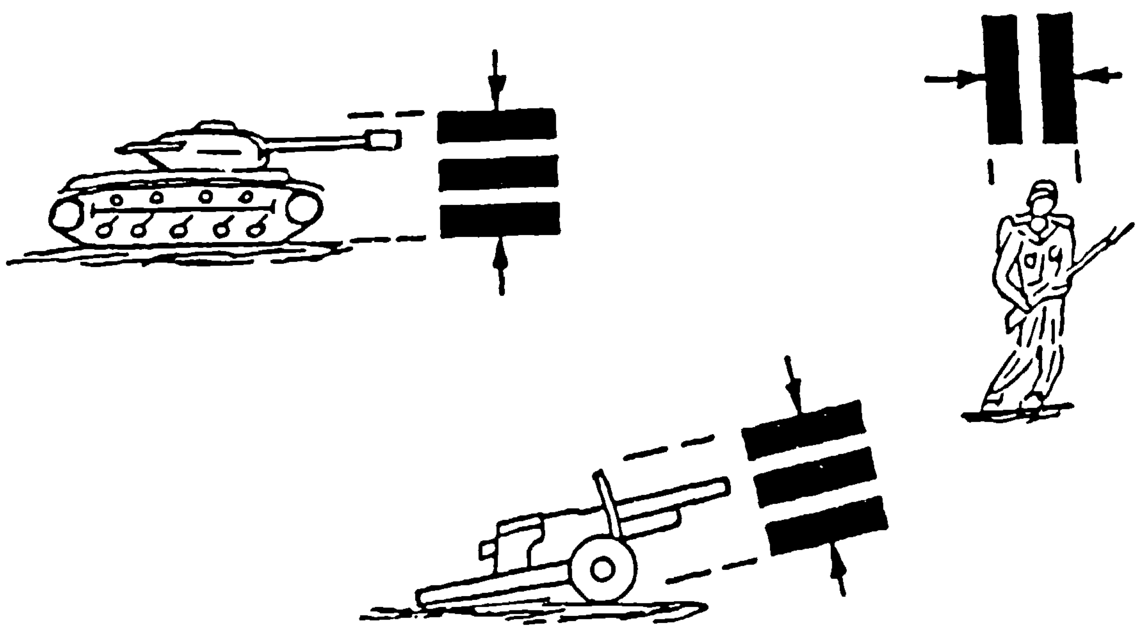

FIGURE 1. METHOD OF OPTICAL IMAGE TRANSFORMATION

Since Johnson set the contrast in the resolution chart to the same level as the contrast in the target, his target transformations were independent of contrast and scene signal to noise ratio. These experiments were conducted under laboratory conditions, and involved only electro-optical sensors.

One of the shortcomings of Johnson's paper was that he did not define the meaning of detection, orientation, recognition and identification. Lucien Biberman (2) provided definitions as shown in Table 2.

TABLE 2. LEVELS OF OBJECT DISCRIMINATION

Discrimination Level	Meaning
Detection	An object is present
Orientation	The object is approximately symmetric or asymmetric and its orientation may be discerned
Recognition	The class to which the object belongs may be discerned (e.g., house, truck, man, etc.)
Identification	The target can be described to the limit of the observer's knowledge (e.g., motel, pickup truck, policeman, etc.)

Other definitions of this terminology are used, but most conform closely to those of Table 2. For example, the Air Force (3) defines target detection as "an object is detected although no further target information can be determined"; target orientation as "target symmetry and dimensional shape are noted"; target recognition as "the target can be placed (e.g., the target is a house, a truck, or a tank)"; target identification as "the target can be described to the limit of the observer's knowledge (e.g., the target is a motel, a pickup truck, or an enemy tank". Further definitions of these and other terms are contained in appendix A.

Johnson did not explain all of the factors which influence target detection, orientation, recognition and identification. There are numerous factors involving not only the target, but the observer and overall scene. Herschel Self (4) has identified a

number of these factors, as shown in Table 3. Self indicated that not all factors listed in each group are independent of other factors under the same heading and the list is neither systematic nor complete. However it does indicate the complexity involved in target detection against a complex background. Many of these factors were downplayed or ignored in Johnson's writings.

TABLE 3. FACTORS INFLUENCING TARGET DETECTION AND RECOGNITION

The scene

1. The size of the picture or displayed image.
2. Numbers, sizes, shapes, and scene distribution of areas contextually likely to contain the target object.
3. Scene objects: numbers, shapes and patterns, achromatic and color contrasts, colors, (hue, saturation, lightness), acutance, amount of resolved details, all both absolutely and relative to the target object.
4. Scene distribution of objects.
5. Granularity, noise.
6. Total available information content and amount of each type of information.
7. Average image brightness or lightness.
8. Contextual cues to target object location.

The target

1. Location in the image format.
2. Location in the scene
3. Shape and pattern.
4. Size, color, resolution(s), acutance, lightness or brightness.
5. Type and degree of isolation from background and objects.

The observer

1. Training
2. Experience
3. Native ability
4. Instructions and task briefing
5. Search habits
6. Motivation
7. Compromise on speed versus accuracy
8. Assumptions.

Another shortcoming of Johnson's paper is the absence of the raw data which was used to compute the average values. Without the raw data it is impossible to determine the accuracy of the averages used. Distribution curves of the laboratory readings should have been provided so that the reader could determine the deviations about the average value over each target by each observer. Also the qualifications and experience of the observers are not

presented. There are numerous characteristics of observers that can change the data dramatically, including the visual accuity of the observer, his training and experience, his search habits in seeking targets, how well he was briefed, his understanding of the task, the amount of time available, his motivation and other physical and psychological factors. These factors have been found to be significant in experiments run by Self (4).

Self states that "upon close examination it is seen that many variables or factors influence detection and recognition of objects. The effects become especially apparent when the time to view an image is limited. Even the common image quality measures in use today turn out to be complex in application and in specification of the obtained values. For example, at different points in the image and in different directions at any given point, obtained image resolution varies. In making predictions of observer performance, it is clear that the effects of even the simple quality aspects depend upon the state of adaptation, visual capabilities, training, instructions, motivation, etc., of the observers. Even observer search patterns are important. Clues from briefing and/or the image context can make a very large difference in performance. Similarly, time to find targets or the probability of finding them within specified time limits is greatly influenced by "image complexity variables, several of which are included in the term 'context'. The influence of target-background interaction effects is clearly established."

Self made the following observations:

1. When a target is not quickly found, searchers tend to 'oversearch' (repeatedly search) likely areas and completely avoid areas dismissed as either unsuitable or as suitable but not containing the target. Frequently targets in contextually unlikely places are not found for minutes even though of adequate size, resolution, and contrast for quick recognition when examined.

2. Despite instructions and training, few observers systematically search a scene until after initial rapid scene-appropriate search fails to find a target. Clearly, search is neither purely systematic nor purely random.

3. Observers sometimes forget which areas have been searched and assume that they have searched an area when they have not. This leads to large time scores when the target is there.

4. Other things being equal, target objects closer to the center of the picture tend to be found quicker.

5. Numerous moving image studies show that subjects under high pressure do hurry to find targets much quicker than those under little or no pressure.

6. Some observers quickly find targets that others with equal training find only after extended search time or do not find at all. Chance factors, such as looking at the right place early in search, are clearly important. However, some subjects are consistently as much as two to three times faster than others over dozens of targets and scenes, and across studies.

7. Averaged across many subjects, identically-appearing target images vary drastically in the time required to detect and to recognize them in different backgrounds (scenes). In other words, there is a strong target-background interaction.

8. When briefing target pictures are rotated relative to the target in the scene, or are of a different size or lightness, target detection and recognition are slower.

Johnson's paper downplayed the significance of the subjective nature of the data and implies a much greater objectivity and precision than was actually achieved.

Some other shortcomings of Johnson's original paper were:

1. the sample targets were relatively small, with small length to width ratios,
2. the target backgrounds, including clutter, were not defined,
3. the characteristics of the targets were not provided,
4. targets with highly recognizable features were not addressed, and
5. the experiments involved optical systems only, with no application to infrared systems.

Despite the shortcomings of the paper, Johnson made a significant contribution to defining requirements for military target acquisition systems by enabling measurement of performance requirements in terms of bar target equivalent spacial frequency. Johnson's experiments were very useful in providing criteria which greatly simplified measurement and test of image intensifiers.

Some sixteen years after publishing his original paper, Johnson collaborated with Walter Lawson on another paper (5) which modified the original work and extended it to cover infrared systems. They added another decision response term, identified as target "classification", which they defined as "the visual act corresponding to perception of the general class of military targets e.g. tracked versus wheeled vehicles". Much of the nomenclature in Johnson's original paper was changed in the second paper. What was referred to as "decision response" is now referred to as "discrimination levels". The later paper emphasizes that the values for the various discrimination levels are "representative values, essentially average values required for 50% probability, and must not be construed as rigid values or optimum values for

specific targets and target aspects". They thus recognized the less than precise nature of the empirical data.

Another change in nomenclature is the change to "cycles for 50% probability" from "resolution per minimum dimension". The later paper changes the average values shown in Table 1 to cycles for 50% probability, as shown in Table 4.

TABLE 4. DISCRIMINATION LEVEL DEPENDENCE ON CYCLES PER CRITICAL DIMENSION

DISCRIMINATION LEVEL	CYCLES FOR 50% PROBABILITY
DETECTION	1.0
ORIENTATION	1.4
CLASSIFICATION	2.5
RECOGNITION	3.0
IDENTIFICATION	6.4

A comparison of Tables 1 and 4 shows that the values associated with the various discrimination levels remained the same, except for recognition, which was reduced from 4 to 3, and classification which was added.

The 1974 paper also introduced the use of minimum resolvable temperature (MRT) for thermal viewers. MRT is used to determine the maximum subjectively resolvable frequency for the effective target temperature difference. The procedure developed by Johnson and Lawson for thermal viewers involved five steps, as shown diagrammatically in Figure 2.

The first step requires determination of the effective target temperature difference and determination of the minimum dimension. The temperature difference associated with the target is the area weighted mean temperature difference calculated from actual target signatures; atmospheric properties are then used together with this temperature difference to establish the effective target temperature (apparent temperature) difference at the observer station. The second step requires calculation of the device minimum resolvable temperature (as a function of spatial frequency); third, determination of the number of resolvable cycles across the target minimum dimension; fourth, determination of the recognition probability (or other discrimination level) from the number of resolvable cycles; fifth, construction of the recognition probability versus range function.

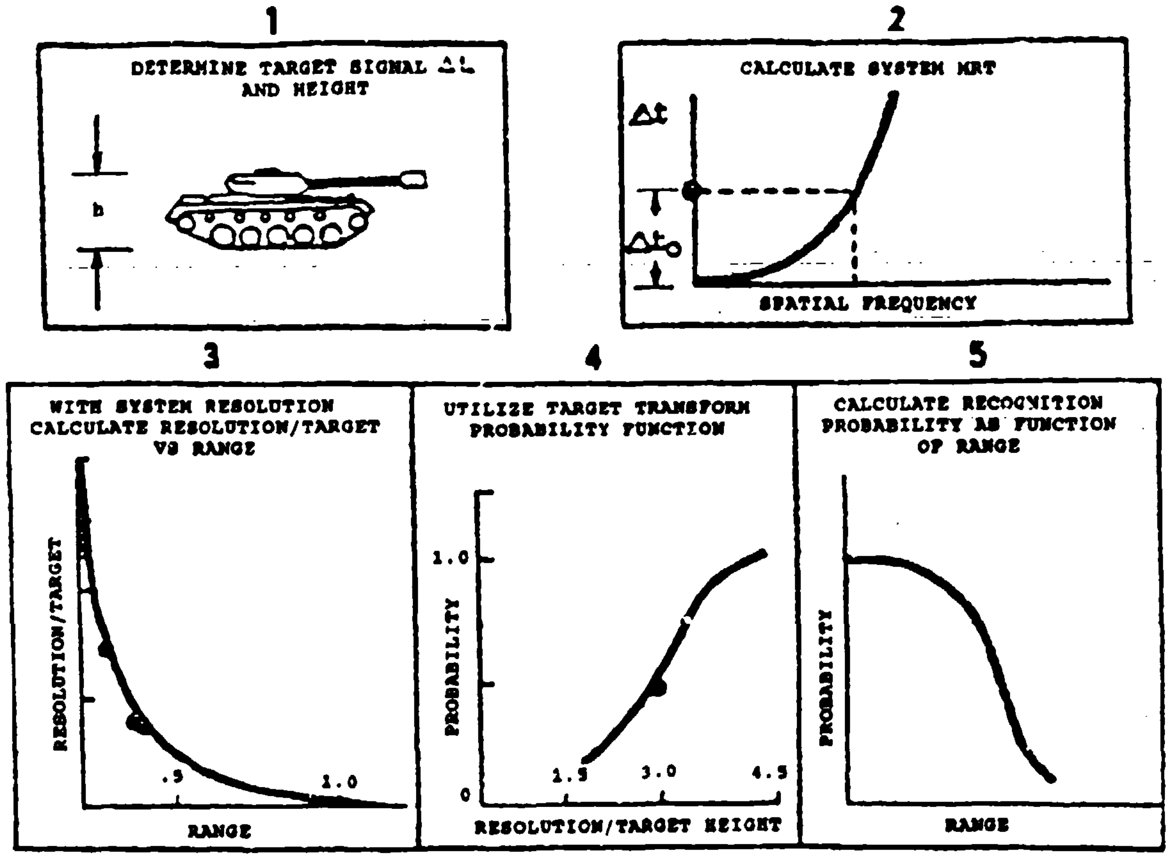

FIGURE 2. GENERAL NIGHT VISION PREDICTION PROCEDURE

To determine the number of resolvable cycles across a target (N), Johnson developed the relationship:

$$N = T_o \frac{h}{R}$$

where: T_o = maximum resolvable frequency
h = minimum target dimension
R = range to target

He also developed a function he referred to as the Target Transform Probability Function (TTPF). This function was derived from laboratory psychophysical experiments in which the ability of observers to discern the nature of tactical targets as a function

of resolvable cycles across the target minimum dimension was measured. The sensor used for these experiments was a low light thermal viewers. The TTPF is a target detection and recognition probability function and is derived from laboratory and field experiments. Figure 3 shows plots of data for target detection and recognition. The two plots to the left are derived from laboratory experiments and the plot to the right is derived from field data. Johnson considered the TTPF to be of fundamental importance in the prediction process. The TTPF replaced the earlier optical image transformations (Table 1) and became the new "Johnson Criteria". The new criteria had broader applicability since it was valid for both optical and thermal viewers.

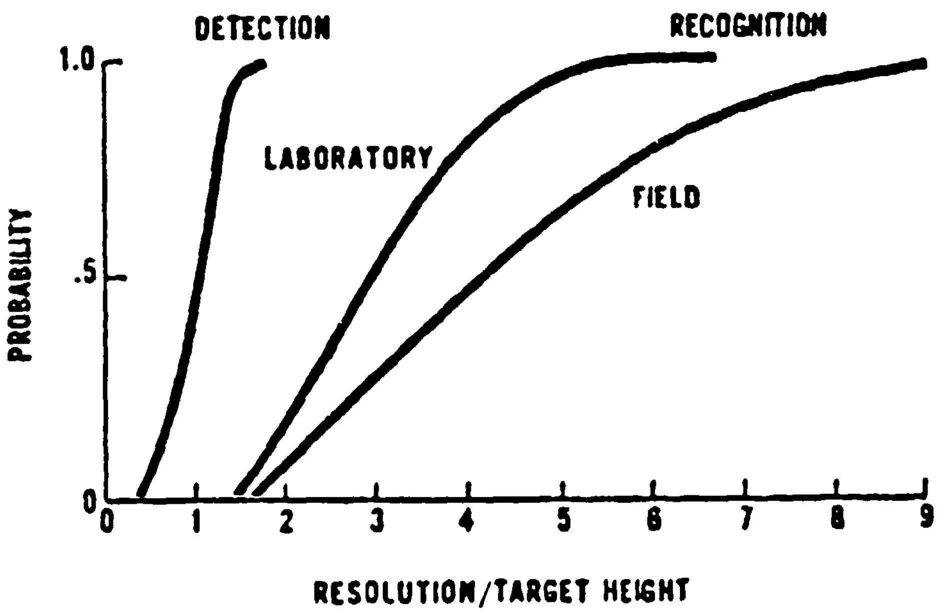

FIGURE 3. TARGET TRANSFORM PROBABILITY FUNCTIONS

Another significant contribution of Johnson's 1974 paper is the extension of the criteria to targets with large length to width ratios (L/W). Since the first paper dealt exclusively with targets with small L/W (2:1), questions had been raised concerning the applicability of the criteria, in particular the TTPF, to recognition and identification of ships and aircraft, i.e. targets with large L/W. Johnson ran experiments, similar to his earlier

work, using scale models of aircraft and ships which were assembled and mounted in a viewing studio to permit accurate light control. A repetitive square wave resolution pattern with a seven to one aspect ratio was mounted in the target plane. The contrast and reflectance of the bar pattern precisely matched those of the scale models. An image intensifier equipped with a variable resolution "aperture plate" was used to view the scale models and the resolution chart simultaneously. A pilot experiment was run in which the ability of a single observer to recognize and identify targets as a function of resolution and aspect angle was determined. The resolution of the viewing device was set to zero at the beginning of each run and then progressively increased until the target was correctly recognized.

Table 5 shows the results of Johnson's experiments with large L/W targets which vary from 6-to-1 for a fighter aircraft to 16-to-1 for a battleship. Also included are two small L/W targets (2-to-1) from his original studies. The table lists the average number of cycles for side view recognition for each target and is given in resolution per minimum target dimension. Johnson stated that "for aspect angle conditions which vary from side viewing (90°) down to near frontal viewing (30°), a single target recognition criterion of 3 cycles would cover practically all targets with a maximum error of about 30%". Johnson noted that this data is based upon observations of a single observer in a limited number of trials.

TABLE 5. SIDE VIEW RESOLUTION CRITERIA OF TACTICAL TARGETS

TARGET	ASPECT RATIO	RESOLUTION/MIN TARGET DIMENSION FOR RECOGNITION
Battleship	16/1	2.8
Destroyer	12/1	4.5
Aircraft Carrier	15/1	2
P. T. Boat	12/1	3.0
Passenger Ship	12/1	3.0
Fighter	6/1	3 cycle
Jet Transport	9/1	2.5 cycle
Tank	2/1	3.5
APC	2/1	3.5

The experiments showed that while detection and recognition criteria for large L/W targets are remarkably close to small L/W targets when viewed from the side, they differ appreciably when viewed from the front or rear. For example, in the case of the battleship, the resolution required for viewing angles of 90° to 30° was approximately 3 cycles. For viewing angles between 30° and 0° (front view) the resolution required nearly doubled to 5.5 cycles. Johnson indicates that "the actual behavior at small aspect view angles is complex and rather unpredictable". The complex nature of small aspect angles was true for aircraft targets as well as ships.

Johnson also noted that "recognition probability is determined by the perception of target features. The larger the perceptible feature set for a given target, and the more detailed the features comprising this set, the greater will be the recognition probability". He indicated that in view of the multiplicity of target signatures and ob[illegible]s, it must be anticipated that recognition probability will change as the perceptible feature set is altered. Since there will be an approximate correlation between the visible feature set and the subjective resolution relative to the target (number of cycles across the target) the recognition probability must change as this relative resolution changes. While Johnson recognized that target features would impact recognition probability, he did not provide any indication of how this would impact the accuracy of the recognition criteria.

Johnson's 1974 paper also addressed the issue of background clutter. He emphasized that the detection function is applicable under conditions which require some degree of target shape discrimination in order to detect the target, i.e. where significant background clutter is present. He also stated that the number of cycles required to attain a particular detection probability can vary significantly depending upon the nature of the background clutter.

Unfortunately this is as far as the discussion of clutter went, and it raised a number of questions as to the significance of background clutter on the validity of the Johnson criteria, especially since Johnson did not provide a definition of clutter. David Schmieder, et al (6) (7) found that indeed the amount and nature of background clutter had a significant impact on the probability of target detection.

The most common clutter measure was scene intensity standard deviation. However this measure has the deficiency of tending to give large clutter values to relatively uncluttered scenes when those scenes possess several intensity modes. Moreover, this definition, like many other amplitude measures, lacks a spatial weighting factor. Both amplitude and spatial measures appear to be required to predict observed trends. Since existing definitions appeared inappropriate, Schmieder, et al, undertook to redefine the term. The definition found to be successful was an "average" scene radiance (or equivalent) standard deviation computed by averaging

the variances of contiguous scene cells over the whole scene and taking the square root of the result. Each cell was square in shape and had side dimensions of approximately twice the target height. This definition can be expressed as:

$$clutter = \left(\sum_{i=1}^{N} \sigma_i^2/N\right)^{\frac{1}{2}}$$

where σ_i is the radiance standard deviation for the i^{th} cell and N is the number of contiguous cells in the scene.

The above definition was judged successful because it yielded higher values for scenes which subjectively appeared to be more complex and cluttered. However, it was also an intuitively satisfying definition because it included both spatial and intensity measures. This definition effectively introduces normalization of intensity on a cell by cell basis. Hence, unlike the conventional intensity standard deviation, it avoids yielding a large clutter value for relatively uncluttered multimodal scenes. In addition, the use of contiguous cells introduces a spatial weighting parameter, i.e., the cell size, which satisfies the intuitive feeling that clutter object sizes close to the target size ought to weigh more heavily in the clutter calculation.

Based upon this definition, experiments performed by Schmieder showed that clutter could be categorized as high, moderate and low, where high clutter exhibited a signal to clutter ratio (SCR) of less than one, moderate clutter an SCR of 1 to 10, and low clutter an SCR greater than 10. The experiments yielded the results shown in Table 6.

From this data it can be seen that for a detection probability of 0.50, the number of cycles (LP/TGT) varies between 0.5 for low clutter and 2.5 for high clutter, with moderate clutter at 1.0. Using the moderate clutter case as a reference, the low clutter condition requires 50% fewer cycles and the high clutter requires 250% more cycles for the same detection probability of 0.50.

Complete curves of detection probability versus required resolution were generated for low, moderate, and high clutter conditions, as shown in Figure 4. The numbers next to the curves represent the measured SCRs, ranging from a high of 39 (very low clutter) to a low of 0.33 (high clutter).

TABLE 6. SUMMARY OF DETECTION CRITERIA FOR BROAD CATEGORIES OF CLUTTER

Detection Probability	Number of Cycles (LP/TGT): Low Clutter (SCR>10)	Moderate Clutter (1.0 ≥ SCR ≥ 10)	High Clutter (SCR < 1.0)
1.0	1.7	2.8	-
0.95	1.0	1.9	-
0.90	0.9	1.7	7.0*
0.80	0.75	1.3	5.0
0.50	0.5	1.0	2.5
0.30	0.3	0.75	2.0
0.10	0.15	0.35	1.4
0.02	0.05	0.1	1.0
0.0	0.0	0.0	0.0

*Estimated

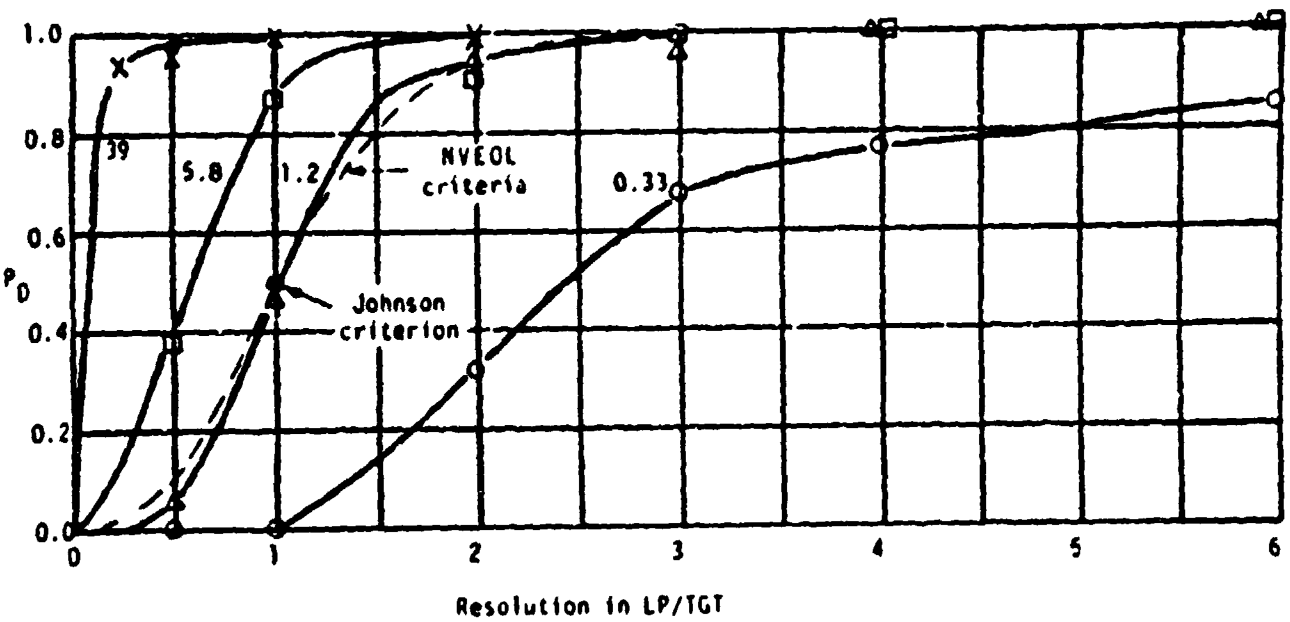

FIGURE 4. MEASURED DATA FROM OBSERVER TESTING FOR INDICATED SIGNAL TO CLUTTER RATIOS (SCR) AFTER CORRECTION FOR CHANCE

From this data, it was concluded that Johnson's criteria (identified as NVEOL criteria in Figure 4) yielded results closely approximating the moderate clutter case (SCR = 1.2). Further it was concluded that "detection performance is a strong function of clutter as well as resolution. Detection range performance prediction models must therefore include clutter effects. Since the number of line pairs per target subtense necessary for detection is inversely proportional to detection range, changes in SCR can be expected to significantly alter range performance."

CONCLUSIONS AND RECOMMENDATIONS

While Johnson's criteria has proven to be a useful tool in determination of electro-optical sensor performance, it is questionable how accurate the results are when applied to a sophisticated system such as the EOTDA. Johnson's criteria ignores or downplays many factors which other investigators have considered significant. Some of the factors ignored by Johnson's critera are: degree of background clutter, characteristics of the observers, meteorological conditions, target shape, target location in a scene, color effects, effects of multiple targets in a scene, and affects of time constraints in the discrimination process.

Johnson's criteria were developed based upon well controlled laboratory tests using models, but were not verified during field tests against actual targets. As any observer can testify, lab conditions and "real world" conditions can be vastly different.

While the various levels of discrimination appear straight forward, they are not, neither in the definition of the terms nor in the cycles per critical dimension (C/CD). The discrimination levels are subjective and are dependent upon the experience of the observer. A highly trained, experienced observer will have a much higher probability of detection, for example, than an inexperienced observer. Further, the C/CD are not precise values. These values are derived through laboratory measurements and are average values over several measurements for several observers for each target type. These average values are then averaged again over all the target types, as shown in Table 1. The resulting values for each discrimination level averaged over the nine targets are only accurate to about ±25%. Since data on individual measurements is not provided by Johnson it is not possible to determine overall accuracy of the discrimination levels. Table 7 shows some of the factors that would contribute to the overall inaccuracy of Johnson's criteria. Since the EOTDA Statement of Operational Need (SON) MAC 509-87 requires an accuracy of ±20% for range outputs, it is highly unlikely the SON requirement can be achieved using Johnson's criteria without significant modification.

TABLE 7. FACTORS CONTRIBUTING TO INACCURACY OF JOHNSON'S CRITERIA

FACTOR	ACCURACY*
Reading Average Per Target	25%
Average Over Small Targets	25%
Average Over Large L/W Targets - Side	30%
Average Over Large L/W Targets - Front/Rear	55%
Clutter Effects - Low Clutter	50%
Clutter Effects - High Clutter	250%
Target Characteristics	200%
Observer Characteristics (Semi-Trained)	100%
Time Limitations	250%

* Estimated impact on resolution accuracy for target detection.

Based upon the foregoing, it is recommended that the Sensor Performance Model be reviewed to determine the degree of inaccuracies due to the application of Johnson's criteria. As a first step, it is recommended that data from field experience be reviewed and compared to predicted values. If there is a significant difference between observed and predicted data, an analysis should be performed to determine what factors have the most significant impact on the results.

This analysis may require a test and evaluation program conducted under field conditions which approximate as closely as possible actual conditions experienced by pilots using the system. Separate field tests may be required using the SPM only, to separate the impact of this model from those of the other models comprising the EOTDA. The analsis and test effort will determine how well the SPM works, and if there are problems, it will identify them so that a plan of action can be undertaken to make required improvements.

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APPENDIX A

DEFINITIONS

ACUTANCE:

Herschel Self 1969 - "Acutance is a measure of edge gradient and is related to the subjective impression of sharpness, but is independent of resolution."

Lucien M. Biberman 1973 - "is a measure of the sharpness of edge expressed in terms of the mean square of the gradient of radiant or luminous flux or density (in a photographic image) with distance from the edge."

ACUITY: See Visual Acuity

BRIGHTNESS:

John Johnson 1958 - for both circular and rectangular object functions.

If C = input target contrast

R_s = intensifier spatial response

B^T_O = output target brightness

B_O = output background brightness

B^B_i = input background brightness

B^T_i = input target image brightness

C^S_O = output image contrast

B^N_O = intensifier background noise

K = intensifier scatter co-efficient

The output image brightness is given by

$$B_O^T = \frac{B_1^T\ T\ G}{4F^2M^2} + B_O^N - R_s\ \frac{(B_1^T - B_1^B)}{4F^2M^2}$$

$$\text{for } B_1^T > B_1^B$$

and

$$B_O^T = \frac{B_1^T\ T\ G}{4F^2M^2} + B_O^N + R_s\ \frac{(B_1^T - B_1^B)}{4F^2M^2}$$

$$\text{for } B_1^B > B_1^T$$

where

F = objective aperture ratio
M = tube magnification
G = tube light gain
T = optical transmission

CLASSIFICATION:

John Johnson and Walter Lawson 1974 - "the visual act corresponding to perception of the general class of military target e.g. tracked versus wheeled vehicles." The number of cycles per critical dimension for 50 percent probability is 2.5 (taken from field results).

CLUTTER:

D. E. Schmieder, M. R. Weathersby, W. M. Finlay and T. J. Doll June 1982, and David E. Schmieder and Marshall R. Weathersby November 1982-"average" scene radiance (or equivalent) standard deviation computed by averaging the variances of contiguous scene cells over the whole scene and taking the square root of the result. Each cell is square in shape and has side dimensions of approximately twice the target height. This definition can be expressed as

$$Clutter = \left(\sum_{i=1}^{N} \sigma_i^2 / N\right)^{\frac{1}{2}}$$

where

σ_i = radiance standard deviation for the i^{th} cell.

N = number of contiguous cells in the scene.

Air Force EO Training 1990 - "A typical target/background scene may contain in addition to a hot (cold) target other "hot (or cold) spots" surrounding the target within the field of view of the guidance sensor. These "hot (or cold)" spots are called thermal clutter."

CONTRAST:

John Johnson 1958 - for both circular and rectangular object functions.

If C = input target contrast

R_s = intensifier spatial response

B_o^T = output target brightness

B_o = output background brightness

B_i^B = input background brightness

B_i^T = input target image brightness

C_o^S = output image contrast

B_o^N = intensifier background noise

K = intensifier scatter co-efficient

then it may be shown that the output image contrast C_0^S is given by

$$C_0^S = \frac{R_s(B_0^T - B_0^B)}{\dfrac{B_0^T - B_0^B}{C} + K\,(B_0^T + B_0^B) + B_0^N}$$

Richard H. Blackwell 1946 - Contrast C was defined by Blackwell as $C = (B_s - B_0)/B_0$ for stimuli brighter than the observation screen, and $C = (B_0 - B_s)/B_0$ for stimuli darker than the observation screen, where B_0 is the brightness of the observation screen (background) and B_s the brightness of the stimulus.

Lucien M. Biberman 1973 - Usually contrast is taken to mean the ratio

$$\frac{\text{(brightness of the brighter) - (brightness of the darker)}}{\text{brightness of the brighter}}$$

David E. Schmieder and Marshall R. Weathersby 1982 - The formula for video contrast is

$$C_v = \frac{\text{target - background}}{\text{background}}$$

Video contrast corresponds to the contrast input to the monitor. Display contrast, on the other hand, is the contrast apparent on the display and is also computed as above except that target and background values must first be converted to display brightness.

R. P. Fiegel, P.S. Gillespie and M. P. Bleiweiss 1991 - For direct view optics, image intensifiers, and television devices the inherent contrast of the dust plume against the background surface is given by

$$C_0 = \frac{R_d - R_b}{R_b}$$

where R_d is the reflectance of the dust plume and R_b is the reflectance of the background.

The inherent contrast for thermal imagers is given by

$$C_0 = T_d - T_b = 0.5$$

Where T_d is the temperature of the dust plume and T_b is the background temperature.

The contrast as observed some distance away is given by

$$C_r = \frac{C_0}{1 + S_g(\frac{1}{T_a} - 1)}$$

where S_g is the sky-to-ground ratio, and T_a is the atmospheric transmittance.

DETECTION:

John Johnson 1958 - By normalizing the resolved line pairs for a critical target dimension the minimum resolution required for detection is 1.0 ± 0.25.

John Johnson and Walter Lawson 1974 - The number of resolvable cycles per critical dimension for 50 percent probability of detection is 1.0.

Lucien M. Biberman 1973 - "An object is present". Johnson's Criteria for the Resolution Required per Minimum Object Dimension versus Discrimination Level

Detection: $2^{+1.0}_{-0.5}$ TV lines,

D. E. Schmieder, M. R. Weathersby, W. M. Finlay, and T. J. Doll June 1982-

1) Detection is the designation of a point as potentially of military interest.

2) Detection involves distinguishing the target from other confusing objects in the scene such as bushes and rocks.

3) Detection occurs when the observer's attention is called to a particular point and is singled out for closer scrutiny.

4) Detection of targets does not involve discrimination between target types such as tank, truck, or jeep but is simply a determination of whether or not an object on the screen is natural clutter or a military target.

5) Detection is said to occur when an observer correctly indicates his decision that an object of interest exists in the field of view.

6) Hot spot detection is the perception of a spatially and temporally persistent spot on a spatially and temporally random noise field.

David E. Schmieder and Marshall R. Weathersby November 1982 - "Target detection probability is a joint function of both signal-to-clutter ratio and resolution."

Air Force EO Training 1990 - "An object is detected although no further target information can be determined."

DFFRACTION LIMIT of resolution:

Lucien M. Biberman 1973 - is the spatial distribution of radiance down to angular spatial frequencies approaching $2D\lambda$, where D is the diameter of the receiving optics and λ is the wavelength of the transmitted information.

IDENTIFICATION:

John Johnson 1958 - By normalizing the resolved line pairs for a critical target dimension the minimum resolution required for identification is 6.4 ± 1.5.

John Johnson and Walter Lawson 1974 - The number of resolvable cycles per critical dimension for 50 percent probability of identification is 6.4.

Lucien M. Biberman 1973 - The target can be described to the limit of the observer's knowledge (e.g., motel, pickup truck, policeman, etc.) Johnson's Criteria for the Resolution Required per Minimum Object Dimension versus Discrimination Level

Identification: $12.8^{+3.2}_{-2.8}$ TV lines,

Air Force EO Training 1990 - "Target identification occurs when the target can be described to the limit of the observer's knowledge (e.g., the target is a motel, a pickup truck, or an enemy tank)."

INFORMATION FLOW in space frequency domain:

John Johnson 1958 - information flow in space frequency domain is the number of resolved line pairs per foot of target space.

$$W = \frac{3440}{a_s L} \quad \text{(resolution bits per foot)}$$

L = distance to target in feet
a_s = minimum anguler subtense of system
W = resolution bits per foot of target space

LOCK-ON: Air Force EO Training 1990 - "At lock-on, the sensor detects enough energy contrast between the target and its background for the seeker to differentiate between the two and the tracker to follow (or track) the target."

MINIMUM DETECTABLE TEMPERATURE (MDT):

Capt Paul T. Beaudoin 1990 - "known as the hot-spot or star detection, describes the situation in which the target is detected as an unresolved spot or blob standing out from the background by virtue of its contrast."

MINIMUM RESOLVABLE TEMPERATURE (MRT):

Capt Paul T. Beaudoin 1990- "describes the situation where the target is perceived as a definite shape, possibly mottled in grey shade, distinguishable from its surroundings."

NUMBER OF RESOLVABLE CYCLES:

John Johnson and Walter Lawson 1974 - The number N of resolvable cycles across the target is given by

$$N = T_o \frac{h}{R}$$

where T_0 is the maximum resolvable frequency, h is the minimum target dimension and R is the range to the target.

ORIENTATION:

John Johnson 1958 - By normalizing the resolved line pairs for a critical target dimension the minimum resolution required for orientation is 1.4 ± o.35

John Johnson and Walter Lawson 1974 - The number of resolvable cycles per critical dimension for 50 percent probability of orientation is 1.4

Lucien M. Biberman 1973 - The object is approximately symmetric or asymmetric and its orientation may be discerned. Johnson's Criteria for the Resolution Required per Minimum Object Dimension versus Discrimination Level

Orientation: $2.8^{+0.8}_{-0.4}$ TV lines,

Air Force EO Training 1990 - "target symmetry and dimensional shape are noted."

RECOGNITION:

John Johnson 1958 - By normalizing the resolved line pairs for a critical target dimension the minimum resolution required for recognition is 4.0 ± 0.8

John Johnson and Walter Lawson 1974 - The number of resolvable cycles per critical dimension for 50 percent probability of recognition is 3.0

Lucien M. Biberman 1973 - The class to which the object belongs may be discerned (e.g., house, truck, man, etc.) Johnson's Criteria for the Resolution Required per Minimum Object Dimension versus Discrimination Level

Recognition: $8.0^{+1.6}_{-0.4}$ TV lines,

Air Force EO Training 1990 - "the target can be placed (e.g., the target is a house, a truck, or a tank)."

RESOLUTION:

Lucien M. Biberman 1973 - The horizontal limiting resolution is the spacing at which one can no longer consistently tell adjacent resolution elements apart.

David E. Schmieder 1988 - "the number of resolvable line-pairs per class object critical dimension provided by the sensor as a function range (the present TDA definition)."

SIGNAL-TO-CLUTTER RATIO (SCR)

David E. Schmieder and Marshall R. Weathersby 1982 - the maximum difference between the target and background radiance divided by the rms clutter radiance for positive contrast targets:

$$SCR = \frac{\text{maximum target value - background mean}}{\text{rms clutter}}$$

while for negative contast targets:

$$SCR = \frac{|\text{minimum target value - background mean}|}{\text{rms clutter}}$$

VISUAL ACUITY:

Lucien M. Biberman 1973 - The detail discrimination threshold of the human eye. Visual acuity is the reciprocal of the angle subtended by the minimum size standard test object that can be resolved 50 percent of the time by a human observer. The angle resolved by a normal eye is approximately 1 minute of arc; normal acuity is therefore the receprocal of 1 minute of arc, i.e., one.

APPENDIX B

TDA ACRONYM/ABBREVIATION LIST

ADPE	Automated Data Processing Equipment
AFATL	Air Force Armaments Test Laboratory
AFGWC	Air Force Global Weather Central
AFWAL	Air Force Wright Aeronautical Laboratories
AGM	Air-Ground Missile
AH	Absolute Humidity
AIM	Aerial Image Modulation
ALSPM	Avionics Laboratory Sensor Performance Model
APC	Armored Personnel Carrier
ASL	Atmospheric Sciences Lab/Air Superiority Lab
ATBSM	Analytics Target/Background Signature Model
ATCCS	Army Tactical Command & Control System
ATM	Atmospheric Transmittance Model
AWS	Air Weather Service
BCD	Battelle Columbus Division
BIC	Battlefield Induced Contaminants
BMP	Target (Armored Personnel Carrier)
BRDF	Bidirectional Reflectance Distribution Function
C^2	Command and Control
CDLOR	Critical Dimension for Lock-On Range
CDMDT	Critical Dimension for Minimum Detectable Temperature
CDMRT	Critical Dimension for Minimum Resolvable Temperature
CFF	Critical Flicker Frequency
CFLOS	Cloud-Free Line-Of-Sight
CI	Image Contrast
CLOS	Clear Line-Of-Sight
CM	Countermeasures
CMRL	Combat Material Research Lab (Army)
CNVEO	Center for Night Vision EO
COMBIC	Combined Obstruction Model for Battlefield Induced Contaminants
CTAC	Classical Target Acquisition Cycle
CTAPS	Contingency Tactical Air Control System Automated Planning System
C_v	Video Contrast
DEC	Digital Equipment Corporation
DET	Detachment
DMA	Defence Mapping Agency
DMF	Demand Moduation Function
DMPI	Desired Mean Point of Impact
DMSP	Defense Meteorological Satellite Program
DR	Detection Range
DRC	Dynamics Research Corporation
D/SMDPSIII	Deployable SMDPSIII
DVTDA	Direct View TDA (Cats Eye Night Vision Goggles)
ΔT	Differential Temperature

EBBT	Equivalent Black Body Temperature
EM	Electro Magnetic
EMAC	Environmental Monitoring And Control
ENSCE	Enemy Situation Correlation Element
EO	Electro-Optical
EOAW	Electro-Optical Analyst Workstation
EOCM	Electro-Optical Counter Measures
EOSAEL	Electro-Optical Systems Atmospheric Effects Library
EOTDA	Electro-Optical Tactical Decision Aids
ETAC	Environmental Technical Applications Center
EXMRT	Threshold for MRT
FAC	Forward Air Controller
FL	Foot Lamberts
FLAPS	Force Level Automated Planning Systems
FLIR	Forward Looking Infrared
FMX	Cut-off (Maximum) Frequency for Sensor
FNOC	Fleet Numerical Operations Center
FOV	Field Of View
GBM	Generic Building Model
GD/PL	Geophysics Directorate/Phillips Laboratory
GLINT	Gated Laser Illuminator for Narrow Television
GTRI	Georgia Tech Research Institute, Electro-Optics Lab
HARM	High-speed Anti-Radiation Missile
HE	High Explosive
HRG	High Resolution Geometry
HVT	High Value Target
ICLTR	Clutter Index
ICOMPL	Index of Scene Complexity
ICO	International Commission on Optics
ICONTR	Index of Scene Contrast
ICSTL	Air Mass Index
IFOV	Instantaneous Field-Of-View
I^2R	Imaging Infrared
IR	Infrared
IRTDA	Infrared TDA
ITDA	Interim TDA
JOT&E	Joint Operational Test and Evaluation
KRC	Keweenaw Research Center, Michigan Technological University, Houghton
LANTIRN	Low Altitude Navigation and Targeting Infrared for Night
LA/LV/LO	Launch-Leave-Lockon
LGB	Laser Guided Bomb
LLLTV	Low Light Level Television
LMRT	Laboratory MRT
LO-LA-LV	Lockon-Launch-Leave
LOR	Lock-On-Range
LOWTRAN	Low Resolution Transmittance Model
LP/TGT	Line Pairs per Target
LRCO	Long Range Capability Objectives
LRD	Laser Rangefinder Designator
L/W	Length-to-Width Ratio

LWIR	Long Wave Infra Red
MAC	Military Airlift Command
MDS	Minimum Detectable Signal (joules/cm^2)
MDSV	Minimum Detectable Signal Value
MDT	Minimum Detectable Temperature
MFT	Multi-faceted Target
MIDAS	Multispectral Imagery Data Analysis System
MIRL	Mobile Infra Red Laboratory
MLOR	Maximum Lock-On Range
MMAC-PAC	Mobile Meteorological Acquisition and Control Package
MMW	Millimeter Wave
Mini-MIRL	Mini Mobile Infra Red Laboratory
MRC	Minimum Resolvable Contrast
MRS	Minimum Resolvable Signal
MRT	Minimum Resolvable Temperature
MSS	Mission Support System
MTF	Modulation Transfer Function
MWIR	Middle Wave Infra Red
NEDT	Noise Equivalent Delta-T
NEI	Noise Equivalent Irradiance
NETD	Noise Equivalent Temperature Difference
NFOV	Narrow Field of View
NOARL	Naval Oceanographic and Atmospheric Research Laboratories
NRL	Naval Research Laboratory
NVEOL	Night Vision & Electro-Optics Lab
NVG TDA	Night Vision Goggles TDA
NVL	Night Vision Lab (Now C^{2}NVEO)
OATS	Optical-Acquisition and Tracking System
OMAC	Orange Measurement And Control Package
OTDA	Operational TDA
PD	Probability of Detection
pdf	probability density function
PGM	Precision Guided Munition
PL	Phillips Laboratory
PNIR	Portable Non-Imaging Radiometer
POC	Point Of Contact
POL	Petroleum, Oil, Lubricant (Tank)
PRESSURS	Prestrike Surveillance and Reconnaissance System
PSR	Pacific Sierra Research Corporation
PTDA	Preliminary TDA
RGTDA	Research Grade TDA
RH	Relative Humidity
RMSD	Root Mean Square Difference
Rr	Lockon Range
RR	Rain Rate
SAC	Strategic Air Command
SAI	Science Applications Incorporated
SAWS	Silent Attack Warning System
SCR	Signal-to-Clutter Ratio
SG	Signal
SIG	Signal
SITF	Signal Intensity Transfer Function

SMDPSIII	Strategic Mission Data Preparation System Phase III
SNR	Signal-to-Noise Ratio
SOF	Special Operations Forces
SPM	Sensor Performance Model
SRM	Sensor Ranging Model
STX	ST Systems Corporation
TA	Target Acquisition
TABILS	Target and Background Information Library System
TAC/IN	Tactical Air Command/Intelligence
TAF	Tactical Air Force
TAMPS	Tactical Aircraft Mission Planning System
TARGAC	Target Acquisition Model
TAS	Target Acquisition System
TCLT	Clutter Temperature
TCM	Thermal Contrast Model
TDA	Tactical Decision Aids
TGT	Target
TH	Threshold
TOT	Time Over Target
TQF	Threshold Quality Factor
TRAM	Target Recognition and Attack Multisensor
TSCEN	Scene Temperature
TSCF	Targeting Systems Characterization Facility
TTPF	Target Transform Probability Function
TV	Television (Visible)
T-72	Soviet Tank Model
UARS	Unmanned Air Reconnaissance System
UMBRELLA	Unified Measurement Blueprint for Rational Experiments Leading to Logical Analysis
VIDEM	Visual Detection Model
VSA	Vertical Structure Algorithm
VTR	Video Tape Recorder
WDA	Weather Decision Aids
WFOV	Wide Field Of View
W/M^2	Watts per Meter Squared
WL	Wright Labs
WRDC	Wright Research and Development Center
WS	Wind Speed
XSCALE	Army VSA
YEFF	Targets Projected Across-Track Dimension
YMAC	Yellow Measurement and Control Package
ZIL	Russian Tank or Truck